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Clinical Effect of Membrane Induction Technology Combined with Platelet-Rich Gel in Repairing Large-Scale Bone Defects

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Abstract: In response to the challenges of insufficient bone healing speed and prevention of complications in the repair of large-scale bone defects, this paper explores the clinical application of this combined technique in large-scale bone defect repair and its impact on bone healing, aiming to evaluate its potential in promoting bone healing and reducing complications. This study selects 30 patients with extensive bone defects, all of whom meet the inclusion criteria. Firstly, all patients undergo standardized imaging examinations and basic assessments before surgery to ensure that the site and extent of bone defects met the surgical conditions. Then, a membrane induction technique is used to cover the defect area, forming a physical barrier that prevents non-bone cells from the surrounding tissue from entering the bone repair area. At the same time, the platelet-enriched part of the patient is used to prepare platelet-rich gel through centrifugation technology, which is applied to the bone defect site to enhance the concentration of local growth factors and promote the proliferation and differentiation of bone cells. Finally, all patients undergo regular radiographic and clinical follow-up after surgery to evaluate bone healing and monitor the occurrence of complications. Data collection includes bone healing progress, clinical symptoms, incidence of complications, and patient quality of life scores. The membrane combined with platelet-rich gel strategy is significantly ahead in multiple core efficacy indicators. This combination therapy shortens the healing period to 12 weeks, which is better than the 16 weeks of the traditional regimen and the 18 weeks of the control group. The complication rate in the membrane + platelet-rich gel group is as low as 5%, which is significantly better than the 15% of the traditional repair group and the 20% of the control group. The treatment method in this paper provides a new and effective treatment option for orthopedic clinics and has good application prospects.

1. Introduction

The repair of large-scale bone defects faces significant challenges, as traditional autologous or allogeneic bone transplantation methods are limited and high-risk. Recently, the innovative therapy combining membrane induction technology and platelet rich gel can create a superior healing environment and rich in growth factors, promote bone regeneration, and show positive effects in small-scale clinical practice, opening up a new direction for treatment. This study aims to explore the clinical potential of this combination therapy in the repair of large-scale bone defects, with the aim of providing patients with more advanced treatment options and breaking through the limitations of traditional treatments.

Although the combination of membrane induction technology and platelet rich gel has shown positive clinical effects in some small-scale studies, the current application in the repair of large bone defects still faces many challenges. Firstly, existing literature mostly focuses on small-scale defects or animal experiments, lacking systematic research on the repair of large-scale bone defects. Second, most studies have ignored the optimization scheme of the combined use of membrane induction technology and platelet-rich gel, such as the influence of gel concentration, membrane type and timing of use. Therefore, how to determine the optimal application conditions and effectively evaluate its bone healing effect in clinical practice remains an urgent problem to be solved. In addition, there is a lack of in-depth research and systematic solutions regarding the prevention of complications of this treatment method, especially infection, bone necrosis and other problems. These issues prompted the research motivation of this article, which is to clinically verify the effect of membrane induction technology combined with platelet-rich gel in the repair of large-scale bone defects and effectively manage and prevent related complications.

In order to achieve the research objectives, this paper will first review and summarize the current research results in the field of large-scale bone defect repair, and explore the respective application backgrounds and advantages of membrane induction technology and platelet-rich gel. Subsequently, this paper will introduce the research design in detail, including the selection of research subjects, the implementation details of the treatment method, and the setting of data collection and evaluation indicators. Specifically, first, this study selects patients with large bone defects that meet the criteria through a prospective clinical trial design and performs detailed imaging and biological evaluations on them. Secondly, the study will evaluate the effect of the combined use of membrane induction technology and platelet-rich gel on bone healing through comparative experiments, especially the repair progress and healing quality of the bone defect area. Finally, this article will delve into the mechanisms underlying the occurrence of treatment complications such as infection and osteonecrosis, and propose preventive strategies. Through quantitative and qualitative analysis, the potential of membrane+platelet rich gel in the repair of large bone defects is revealed. Compared with traditional therapy, it aims to provide new treatment ideas for clinical use and lay a foundation for subsequent research.

2. Related work

In the field of extensive bone defect repair, the combination of membrane induction technology and platelet rich gel has gradually become a research hotspot. This method has shown promising prospects in promoting bone tissue regeneration, improving bone healing speed, and reducing postoperative complications. Fan et al. [1] studied the effect of sustained-release dexamethasone-modified sericin hydrogel scaffolds on promoting the repair of mandibular defects in rats. Guo et al. [2] studied the use of 3D printed metal prostheses to reconstruct large bone and joint defects after extremity bone tumor resection, further opening a new era in the repair and reconstruction of large bone defects. Han et al. [3] studied the effect of drug-loaded thermosensitive hydrogel on regulating macrophage M2 polarization to promote the repair of osteoporotic bone defects. Qi et al. [4] used surface-modified 3D printed scaffolds to promote bone defect repair through bone immune regulation. Wang et al.[5] used magnesium-modified acellular bovine bone matrix to enhance osteogenesis and mandibular defect repair. Therefore, the clinical application of membrane induction technology and platelet-rich gel is mainly focused on bone trauma repair, bone defect repair after bone tumor resection, and bone repair after spinal surgery. However, existing studies have mostly focused on small-scale defects, and the specific operating conditions, optimization strategies and long-term effect evaluation of treatment methods are still insufficient.

As an autologous biomaterial, platelet-rich gel has been widely used in the field of soft tissue repair and bone healing. It can effectively promote the recovery of blood supply to bone defects through the release of growth factors by high concentrations of platelets, thereby accelerating the bone healing process. The application of membrane induction technology also provides strong support for the effect of platelet-rich gel. Du et al. [6] believed that shape memory polyester scaffolds promote the repair of bone defects by enhancing osteogenesis and mechanical stability. Peng[7] believed that shape memory polyester scaffolds can promote bone defect repair by enhancing osteogenesis and mechanical stability. Li et al.[8] used biomodified implants as therapeutic bioresorbable materials for bone defect repair. Jin et al.[9] studied the effect of bone grafting on the repair of alveolar bone defects distal to the second molar after extraction of impacted mandibular third molars. Lin et al. [10] believed that shikonin could promote the repair of periodontal bone defects and osteogenic differentiation of bone marrow mesenchymal stem cells in rats through receptor pathways. However, current research mainly focuses on the preparation and biological properties of platelet-rich gels, and specific discussions on their combined use effects and treatment strategies in large-scale bone defects are relatively limited. Most existing studies remain at the animal experiment stage, lack in-depth analysis and verification of clinical data, and fail to fully evaluate possible complications during treatment and their prevention measures.

3. Methods

3.1 Study Design and Sample Selection

This study adopted a prospective clinical trial design to evaluate the effect of membrane induction technology combined with platelet-rich gel in the repair of large-scale bone defects. The study subjects were patients aged between 18 and 70 years who were diagnosed with bone defects caused by trauma or tumor resection. All selected patients underwent imaging examinations (such as X-rays) before surgery to determine the size and location of the bone defect and ensure that they met the conditions for surgical repair. Exclusion criteria included patients with severe comorbidities (such as severe cardiovascular and cerebrovascular diseases, diabetes, etc.), patients who had recently received other bone repair treatments, and patients with immune system diseases or who used immunosuppressants. In the final research sample selection, a total of 30 patients who met the criteria were included in this paper and randomly divided into an experimental group and a control group, with 15 people in each group. The experimental group received membrane induction technology combined with platelet-rich gel treatment, while the control group received traditional autologous bone transplantation treatment.

3.2 Specific Operation of Membrane Induction Technology

The core of membrane induction technology is to promote the regeneration and healing of bone tissue by covering the bone defect area with biocompatible membrane materials[11-12]. First, after the patient is anesthetized, a standardized surgical incision is used to expose the bone defect site, ensure that the edges of the bone defect are clean, and remove necrotic or damaged bone tissue. Subsequently, appropriate membrane materials are selected according to the size and shape of the defect area. These membrane materials are usually degradable polymer membranes or biocompatible materials that can gradually degrade during the bone healing process without leaving any residue. The main function of the membrane is to create a closed environment to prevent non-bone cells (such as chondrocytes, adipocytes, etc.) from entering the repair area, while retaining beneficial components such as growth factors and stem cells to promote the proliferation and differentiation of bone cells.

The membrane material is firmly covered on the surface of the bone defect area by fine fixing means, such as small staplers or biocompatible adhesives. After fixation, the stability and position of the membrane are further confirmed to ensure that it is not disturbed by external forces. Finally, the surgical incision is sutured, the patient's postoperative function is restored, and postoperative management begins. Considering the repair process of the bone defect area, the effect of the membrane can be quantified by the following equation:

$$F_{bone} = k_1 \cdot A \cdot G_{growth} - k_2 \cdot \Delta t \quad (1)$$

F_{bone} represents the overall progress of bone healing, A is the area covered by the membrane, and G_{growth} is the effect of growth factor concentration, reflecting the ability of the membrane material to regulate the release of growth factors; G_{growth} is a constant related to membrane compatibility and biological function; k_2 is the membrane degradation rate coefficient; Δt is the time interval of the membrane material degradation process. This formula indicates that the area of the membrane and the concentration of growth factors have a positive impact on the bone healing process, while the degradation rate of the membrane has a certain negative impact on bone healing.

In order to better simulate the repair progress of bone defect area, a joint repair progress model can be established considering the combined effect of membrane induction technology and platelet rich gel, as shown below:

$$P_{repair}(t) = P_0 + \int_0^t \big(k_3 \cdot F_{bone}(t) + k_4 \cdot R_{GF}(t)\big)\ dt \quad (2)$$

$P_{repair}(t)$ represents the repair progress at time t, P_0 is the initial state before repair (usually set to 0); $F_{bone}(t)$ is the progress of healing; $R_{GF}(t)$ is the release rate of growth factors; k_3 and k_4 are constants related to bone healing and growth factor release, reflecting the contribution of these two factors to the repair progress.

3.3 Preparation and Application of Platelet-Rich Gel

Platelet rich gel is a concentrate prepared from platelets in patients' autologous blood. It is rich in a large number of growth factors, such as platelet-derived growth factor, transforming growth factor β, etc. These growth factors play a vital role in the process of bone healing. Firstly, 10-20 milliliters of peripheral blood were collected from the patient before surgery, and the blood was divided into three layers using a centrifuge: the red blood cell layer, the plasma layer, and the platelet rich plasma layer. Then, the platelet rich layer is extracted and mixed with the biological gel matrix to form a platelet rich gel. This process needs to be carried out in a strict sterile environment to ensure the quality and biological safety of gel. The application of platelet rich gel is to directly fill it in the membrane covered bone defect area. Through this process, the growth factors in the platelet rich gel can be released locally, promote the formation of new blood vessels, and stimulate the proliferation and differentiation of bone cells, thus accelerating bone healing. The role of gel is to locally enhance the repair effect, and its own degradation characteristics match the degradation rate of membrane induction technology, so that the repair area can maintain a suitable environment throughout the healing process.

The release rate R_{GF} of growth factors in platelet rich gel can be expressed by the following model to describe its time-varying release process in the repair region:

$$R_{GF}(t) = R_0 \cdot e^{-\lambda t} \tag{3}$$

R_0 is the initial growth factor concentration; λ is the decay constant, describing the degradation rate of the growth factor in the gel. This model reflects that the growth factor is gradually released over time and its concentration decays during the biodegradation process.

In order to quantitatively evaluate the progress of bone healing, the change in bone density can be used to indicate the bone healing status. The change in bone density $\Delta\rho$ can be calculated using the following formula:

$$\Delta\rho = \frac{\rho_{final} - \rho_{initial}}{\rho_{initial}} \times 100\% \tag{4}$$

ρ_{final} is the bone density at a certain point in time after surgery; ρ_{intial} is the initial bone density before surgery.

3.4 Data Collection and Evaluation Indicators

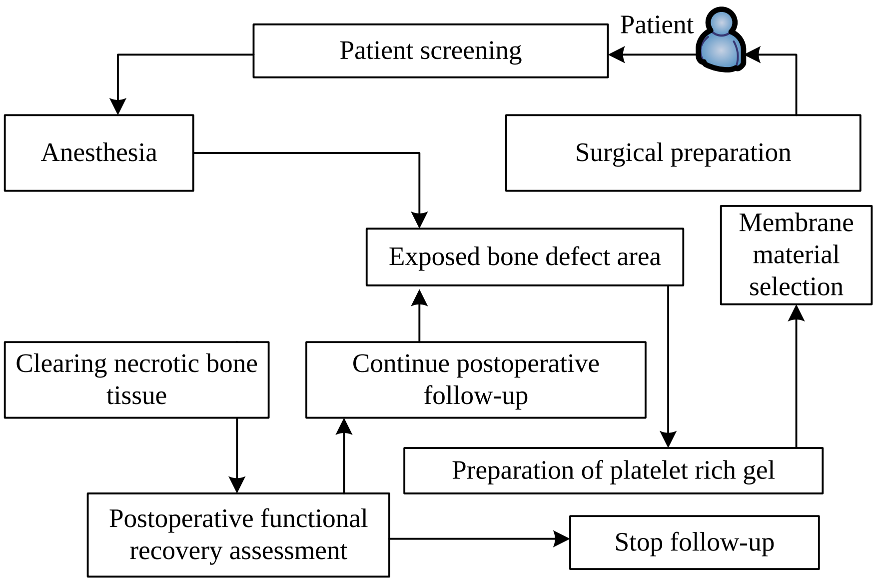

Figure 1: Effects on bone healing and prevention of related complications

In order to comprehensively evaluate the effect of membrane induction technology combined with platelet-rich gel in the treatment of large-scale bone defects, this study adopted a multi-dimensional evaluation system covering clinical, imaging and biological data. First, in terms of clinical evaluation, a comprehensive assessment is mainly conducted by recording the patient's postoperative pain score, functional recovery (such as joint range of motion, weight-bearing capacity, etc.), and the patient's quality of life score. In addition, postoperative complications (such as infection, bone necrosis, foreign body reaction, etc.) will also be strictly monitored to ensure the safety of treatment. Radiographic evaluation evaluates the progress of bone healing and the quality of bone defect repair through regular X-ray examinations. Especially at 6, 12 and 24 weeks after surgery, radiographic examinations can clearly show the degree of bone healing and evaluate the repair of bone defects by comparing with preoperative images. Biological evaluation involves collecting blood samples from patients before and after surgery and testing biomarkers related to bone metabolism (such as bone-specific alkaline phosphatase, osteocalcin, etc.) to monitor the biological response of bone healing. At the same time, follow-up will be conducted for the experimental group and the control group six months after surgery to record the long-term effects of bone healing and possible complications of the patients. Through these evaluation indicators, we can objectively and comprehensively understand the clinical effect of membrane induction technology combined with platelet-rich gel therapy and compare it with traditional treatment methods. The impact on bone healing and the prevention plan of related complications are shown in Figure 1.

4. Results and Discussion

4.1 Evaluation of Bone Healing Effect

Bone healing effect is one of the core evaluation indicators of this study. The healing of the bone defect is evaluated through imaging examinations (such as X-rays) and clinical examinations. The main evaluation indicators include changes in bone density, bone healing time, and healing quality.

The healing time and healing quality scores of different groups are shown in Table 1.

Table 1: Healing time and healing quality scores in different groups

Group	Healing time (weeks)	Healing quality score (1-5)
Membrane+platelet rich gel group	12	4.8
Traditional Restoration Group	16	3.9
control group	18	3.2

The membrane-bound platelet-rich gel strategy performs well in bone defect repair. Its healing time is only 12 weeks, which is significantly shorter than the 16 weeks of the traditional repair group and the 18 weeks of the control group, highlighting the high efficiency of accelerating bone healing. This advantage may be due to the effectiveness of high concentrations of growth factors in platelet-rich gel in promoting cell proliferation and new bone formation, coupled with membrane induction technology that optimizes the repair environment and accelerates blood supply and periosteum regeneration. In terms of healing quality, the score of the membrane + platelet-rich gel group is as high as 4.8, far exceeding the 3.9 of the traditional group and 3.2 of the control group, indicating better recovery of bone tissue structure, strength and function. The protective membrane layer formed by membrane induction technology reduces external interference, and the platelet-rich gel accelerates the proliferation and differentiation of bone cells, jointly improving the quality of healing. In contrast, traditional methods are limited by regenerative capacity and have poor bone defect repair effects. In summary, the membrane + platelet-rich gel strategy has excellent healing time and quality, verifying its innovative potential and clinical application value in bone defect repair, and opening up a new path for bone defect treatment.

The preoperative and postoperative bone densities of different groups are shown in Figure 2.

The combination of membrane and platelet rich gel can significantly improve bone mineral density. Before surgery, the bone density of this group is 0.45 g/cm ^{3}, and after surgery, it jumps to 1.25 g/cm ^{3}, indicating good bone healing. This effect can be attributed to the growth factor in platelet rich gel, which effectively promotes the proliferation and differentiation of bone cells, accelerates bone healing, and significantly increases bone density. This increase is not only a key indicator of bone healing, but also an important basis for evaluating therapeutic efficacy. This combination therapy has unique advantages in promoting bone regeneration due to its efficient bone repair ability and high biocompatibility. By improving local blood supply, increasing nutrition, and reducing bone resorption, it further enhances bone density recovery and provides strong support for extensive bone defect repair.

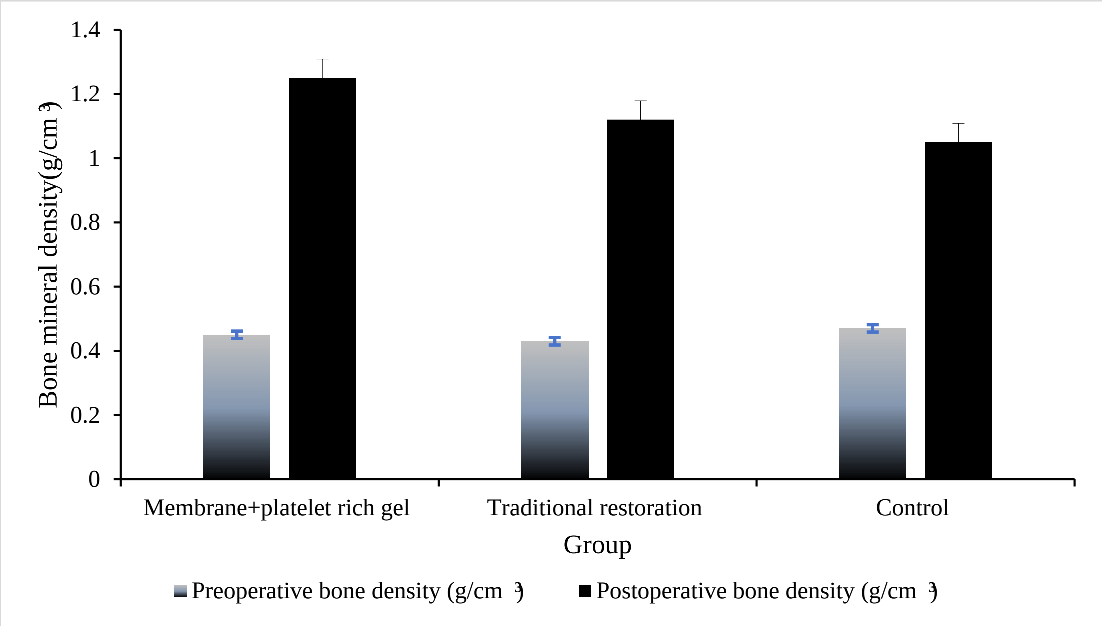

Figure 2: Bone density before and after surgery in different groups

4.2 Progress of Bone Defect Repair and Complications

The evaluation of repair progress and complications is of great significance for clinical application. This study monitored complications during postoperative follow-up and recorded the staged progress of bone defect repair. The progress of bone defect repair and complications are shown in Figure 3.

The membrane combined with platelet-rich gel strategy has shown excellent results in bone defect repair. Its complete healing rate is as high as 85%, far exceeding the 70% of the traditional repair group and 55% of the control group. Especially in cases of severe bone defects, this combination significantly accelerates the bone regeneration process and shortens the healing time through the synergistic effect of membrane induction technology and platelet-rich gel. It is worth noting that its partial healing rate is only 10%, much lower than the 20% in the traditional group and 30% in the control group, highlighting its ability to reduce incomplete healing and enhance overall efficacy. At the same time, the non-healing rate is controlled at 5%, which is also much lower than other groups. In terms of safety, the complication rate of the membrane + platelet-rich gel group is as low as 5%, significantly better than the 15% of the traditional repair group and the 20% of the control group. This significant difference is attributed to the strategy creating more ideal healing conditions for bone defect areas, effectively promoting bone tissue regeneration, and reducing postoperative risks. Therefore, the combination of membrane and platelet rich gel shows significant advantages in improving healing efficiency and reducing complications, providing an efficient and safe new way for the treatment of bone defects, and has broad clinical application prospects.

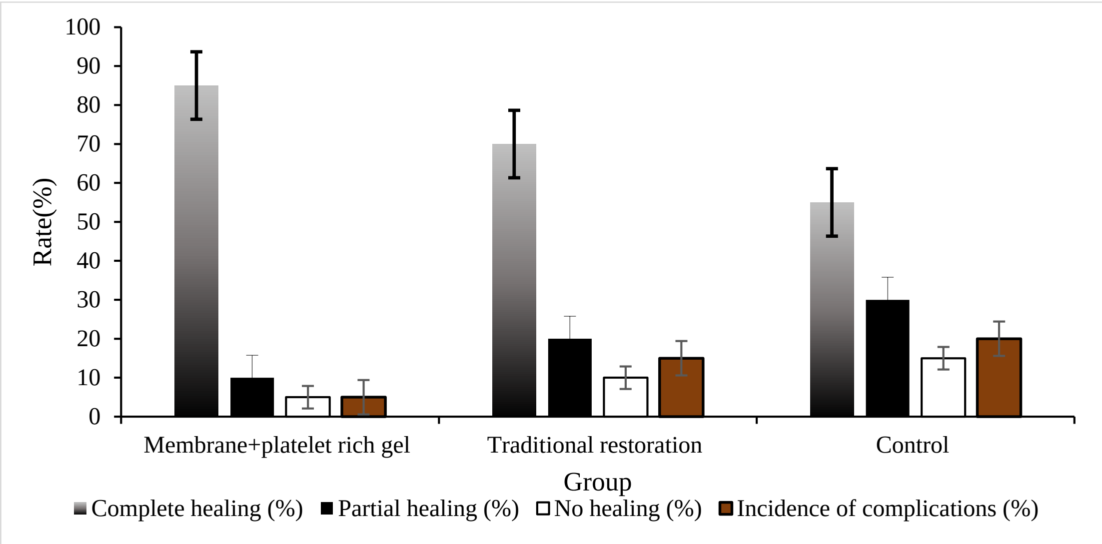

Figure 3: Progress of bone defect repair and complications

4.3 Comparative Analysis with Traditional Repair Methods

In order to evaluate the comparative advantage of membrane induction technology combined with platelet rich gel, this study compared its bone healing effect, repair progress, complication rate and patients' quality of life with traditional repair methods. The comparative analysis data with traditional repair methods is shown in Table 2.

Table 2: Comparative analysis data with traditional repair methods

Comparison items	Membrane+platelet rich gel group	Traditional Restoration Group	control group
New bone formation rate (%)	90%	75%	60%
Bone healing time (weeks)	12	16	18
Patient functional recovery score (1-10)	8.6	7.3	5.2

Analysis of data shows that the membrane-based platelet-rich gel strategy is significantly ahead in multiple core efficacy indicators. This combination therapy shortens the healing period to 12 weeks, which is better than the 16 weeks of the traditional regimen and the 18 weeks of the control group. This suggests that the growth factor in the platelet-rich gel accelerates the growth and differentiation of bone cells, shows excellent safety and postoperative mobility, and has great clinical application prospects, especially in bone healing and functional improvement.

5. Conclusion

This study found that the combination of membrane induction technology and platelet-rich gel for large-scale bone defect repair significantly improved bone healing efficiency, far exceeding traditional methods, and reduced the average healing time to 12 weeks, marking an important progress in the field of bone regeneration and effectively accelerating the recovery process. At the same time, this strategy also performed well in reducing the risk of complications (only 5%) and improving patients' functional recovery level, which strongly demonstrated its unique value in improving patients' quality of life. In clinical practice, this combined therapy has brought a new, efficient and safe repair approach to patients with large bone defects. It not only shortens the treatment cycle, but also optimizes the healing quality, reduces postoperative adverse reactions, and comprehensively improves the rehabilitation experience. Its innovative fusion of membrane induction technology and the essence of platelet-rich gel has opened up a new perspective for the treatment of bone defects. Looking into the future, as research deepens, this technology has great potential for application in multiple fields such as orthopedics and dentistry, injecting new vitality into the development of related disciplines and providing more abundant solutions to the challenges of bone defect repair.

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